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Retrieving the Vanishing Liquidity Effect—A Threshold Vector Autoregressive Model

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This paper employs a threshold vector autoregressive (TVAR) model where the data is subdivided into low and high inflation regimes. Monetary policy is endogenized in this framework and two different measures of monetary policy, viz. NBR and M1, are investigated. The interest rate is hypothesized to respond inversely to increased monetary growth in the low inflation regime and positively to increased monetary growth in the high inflation regime. In the low inflation regime, expansionary monetary policy shocks are found to depress the interest rate over 10 and 5 periods for nonborrowed reserves and M1 growth, respectively. Whereas, in the high inflation regime, both measures generate positive responses. It follows that the hypothesized threshold behavior between money and the interest rate is supported regardless of monetary measures. © 1999 Elsevier Science Inc.

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I. Introduction

Whether an increase in the money supply temporarily lowers interest rates through the liquidity effect or not has long been a critical macroeconomic issue. Previous research has focused attention on the dynamic relationship between these two variables by employing univariate models. For example, using samples prior to the 1970s, Cagan and Gandolfi (1969) and Gibson (1970) both found that the interest rate declines from four to nine months following an increase in monetary growth, and then begins to rise. However, the liquidity effect is much shorter lived or even nonexistent, when data from the 1970s and

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beyond are considered. For instance, using a sample period from 1973–1979, Melvin (1983) showed that, by the second month, the interest rate rose sharply above the initial rate after an increase in monetary growth. Similarly, using a sample period of quarterly data covering 1975:4–1983:3, Mishkin (1981, 1982) and Reichenstein (1987) also failed to find evidence supporting a short-term liquidity effect. Mehra (1985), in a study using data from both low and high inflation periods, found that a liquidity effect occurred in the 1950s and early 1960s, but this effect had all but disappeared in the subperiod beginning in the 1970s and ending in 1979 or 1983.

Friedman (1968) attempted to reconcile this issue by contending that the timing of the effects of monetary growth on interest rates crucially depends on the perception of inflationary pressure. According to Friedman (1968), there are four effects, which may be characterized as liquidity, price, output and inflationary expectations effects, which result when monetary shock occurs. If the expected inflation rate is low, excess monetary growth causes downward pressure on the interest rate. In response to this imbalance of the money market, the interest rate declines in order to reestablish a new market equilibrium. The interest rate is thus observed to decline immediately after a positive monetary shock. Subsequent to this, the influence of price and output effects appears after several periods. Thus, the liquidity effect dominates other effects in the short run. In contrast, when the prevailing inflation rate is persistently high, the inflationary expectations effect during this period may be sufficiently strong and prompt to overpower the short-run liquidity effect. This is made all the more possible by the fact that during this period, prices are more flexible. Hence, the interest rate rises after increased growth of money stock, even in the short run.

The theoretical argument made by Friedman (1968) emphasizes that the response of interest rates to a change in money is a function of inflationary regimes. Empirical studies, on the other hand, have tackled this issue only in an approximate manner. These studies typically have split the data at a particular date into low- and high-inflation periods. A low-inflation period implies that, on an average, inflation is below a critical value. The possibility of occasional high inflation during this period is not, however, excluded. Thus, the inverse relationship expected in the low-inflation period may be extenuated by these sporadic observations of high inflation. The high-inflation period suffers from a similar lack of consistency. Hence, whether or not the data can be grouped in a more revealing manner (i.e., more consistent with the Friedman (1968) argument) is worth pursuing.

The threshold model proposed by Tong (1983), using the inflation rate as the threshold, is an ideal tool for separating the sample into low- and high-inflation regimes.[1] Although utilization of the Tong (1983) threshold model is promising in this regard, it is nevertheless limited by its use of a univariate framework. In the univariate setting, the money supply and, hence, the money stock is assumed to be exogenously controlled by the central bank. A more realistic approach would be to recognize that commercial banks as well as the public can also influence the money supply. It follows that movements in the money supply may not reflect the intentions of monetary authorities, but may be due instead to feedback from other economic forces. Leeper and Gordon (1992), Gordon and Leeper (1994), Christiano and Eichenbaum (1992), Christiano et al. (1994), Leeper (1995), Sims and Zha (1994), and Pagan and Robertson (1995), to name a few, have stressed that the monetary policy shocks cannot be successfully identified in a univariate framework.

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[1] Shen and Hakes (1995) also used the inflation rate as a threshold variable to separate the central bank's reaction function into two regimes.

Interpretation of the response of the interest rate to a monetary policy shock may therefore be mistaken, if one uses the univariate process. Alternatively, a multivariate framework, such as a vector autoregressive model (VAR), has been suggested to study such issues. The dynamic impact on the interest rate from a monetary policy shock (the impulse response function, IRF) is typically employed to evaluate the effectiveness of the liquidity effect.

This paper extends the Tong (1983) univariate threshold model to a multivariate framework, which is termed a threshold VAR (TVAR). The TVAR, though still in its infancy, is an ideal tool for estimating the liquidity effect in different regimes. This approach retains the merit of being able to separate the data into two regimes. Furthermore, the TVAR can be used to properly assess the Friedman (1968) hypothesis and, being multivariate in nature, can more precisely identify the relevant monetary policy shocks. In addition, the TVAR allows us to consider a model in which the inflation regime is endogenous. For example, assuming that the economy is currently characterized as having a low-inflation regime, an expansionary monetary policy depresses the interest rate, thereby stimulating investment. The rise in investment, in turn, pushes the price level upward. The rise in the price level, if sufficiently strong and persistent, can switch the system to a high-inflation regime. Once strong inflationary expectations are formed in the high-inflation regime, the liquidity effect may prove to be dominated by such expectations. Accordingly, the low-inflation regime, initiated by a negative response of the interest rate to money, gives way to a new response pattern of the interest rate to monetary policy with the passage of time. Consequently, money, interest, and output shocks can influence inflationary conditions, which in turn affect economic activities.

Our empirical result has several crucial implications. Firstly, it assists in accounting for different results which have been reported in the literature. Normandin and Phaneuf (1996), in summarizing the findings in the literature, indicated that the existence of the liquidity effect depends on the proxy used to represent monetary policy. No liquidity effect is detected if monetary policy is measured by M1 [Leeper and Gordon (1992); Christiano and Eichenbaum (1992)], whereas a liquidity effect may be detected if the quantity of nonborrowed reserves (NBR) is employed [Christiano and Eichenbaum (1992); Strongin (1995)]. Herein, both M1 and NBR are considered in order to examine the sensitivity of our hypothesis. The results obtained strongly support threshold behavior when NBR is employed, while weakly supporting the same behavior using M1. Hence, threshold behavior offers an interesting alternative for explaining the relationship between interest rates and monetary policy shocks. Employing the whole or sub-sample (split by date) runs the risk of simply mixing two different responses of the interest rate.

The results presented here help to clarify the transmission of monetary policy. Whether or not monetary policy influences the economy through a money view or credit view has recently attracted a lot of attention [Kashyap et al. (1993); Bernanke et al. and Gilchrist (1996); Bernanke and Gertler (1995)]. A stronger effect of monetary growth on output is observed when credit market (properly defined) conditions exceed a certain threshold than when these conditions are below the threshold [McCallum (1991); Balke and Chang (1996)]. Furthermore, the high-inflation regime detected here roughly matches the above authors' *tight* credit regime.[2] Hence, it may be that monetary policy affects economic

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[2] High-inflation regimes occurred during the two oil-shock periods, which correspond to two of the six tight-credit regimes.

activities through a money view during low-inflation regimes, but through a credit view during high-inflation regimes. We leave this aspect to future study.

The rest of this paper is organized as follows. The threshold model is introduced in the next section. Data sources and nonlinearity tests are discussed in Section III. Empirical studies from both univariate and multivariate processes are provided in Sections IV and V, respectively. Concluding remarks are made in Section VI.

II. A Threshold Model

In this section, we examine how monetary policy shocks affect the interest rate in a univariate process. As suggested by Friedman (1968), the inflation rate acts as propagator of the shocks, and serves to induce regime switching and asymmetry. Threshold models are therefore a relatively simple and intuitive way to capture some of the nonlinearity implied by this phenomena.

The univariate threshold model proposed in this paper is:

$$i_t = A^0(L)i_{t-1} + B^0(L)X_t + [A^1(L)i_{t-1} + B^1(L)X_t]I(\pi_{ct} > r) + \varepsilon_t, \tag{1}$$

where X_t denotes a vector of exogenous (or predetermined) variables, including monetary policy shocks; $A^0(L)$, $A^1(L)$, $B^0(L)$ and $B^1(L)$ are lag polynomials; π_{ct} represents a measure of inflationary conditions (see below); r is the threshold critical value, and $I[\cdot]$ is an indicator function which equals 1 when $\pi_{ct} > r$, and zero otherwise. This model allows the dynamic response of the interest rate to change if the indicator of inflationary conditions variable, π_{ct}, exceeds a critical threshold value, r. The asymmetric effect of monetary policy on the interest rate during different inflation regimes can be determined by examining the corresponding coefficients of B^0 and $B^0 + B^1$.

Inflation rates below (above) the threshold value constitute low (high)-inflation regimes. The threshold value can be viewed as a turning point at which the liquidity effect is superceded by the inflationary expectations effect. Data in the low-inflation regime are generated by market behavior in which economic agents slowly adjust their inflationary expectations. By virtue of this, interest rates fall when the monetary authority increases the money supply. On the other hand, in the high-inflation regime, the speed of adjustment of inflationary expectations is quite rapid. The dominance of the inflationary expectations effect is therefore likely to produce a non-negative empirical correlation between interest rates and the growth rate of the money supply, thereby overpowering the liquidity effect.[3]

Before estimation, a nonlinearity test has to be implemented to determine whether threshold behavior is rejected or not. Four nonlinear tests including the *F* test proposed by Tsay (1986), the augmented *F* test proposed by Luukkonen et al. (1988), the threshold test proposed by Tsay (1989), and a general nonlinearity test, also proposed by Tsay (1991), are therefore carried out here. Adhering to the nomenclature by Cao and Tsay (1992), these four test statistics are referred to as ORG-F, AUG-F, TAR-F and GEN-F, respectively. For brevity, the four test statistics are not introduced here but can be found in the above references.

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[3] Some researchers have shown interest in investigating the responses of the interest rate to changes in monetary policy operating procedures. Hence, the sample is often split at the date October 6, 1979 in order to examine the implications of policy changes. As the aim of these papers has focused on the impacts of policy change, the suggestions given in this paper does not apply to them.

If linearity is rejected, estimation is implemented next. The estimation of equation (1) requires knowledge of both the inflation threshold variable, π_{ct}, and the threshold value, r. The two methods which have been proposed to estimate threshold variables and values include the Tong (1983) grid search method and the Tsay (1989) arranged autoregression method. This study has employed the Tong (1983) method to search for the threshold variables and values, as the method is more widely used than the latter.[4] Because the effects of inflationary expectations may take some time to manifest themselves, the threshold variable, π_{ct}, might be composed of lagged values of the actual inflation rate (π_t) or its moving average. Taking a similar approach to that of Balke and Chang (1996), the following nine alternative threshold variables are considered for the univariate process:

$$\pi_{ct} = \sum_{j=0}^{k-1} \pi_{t-d-j}/k \text{ for } (k = 1,\ d = 1, 2, 3),\ (k = 2,\ d = 1, 2),\ (k = 3,\ d = 1), \tag{2}$$

where k denotes the length of the moving average, and d the delay parameter. A search is conducted for the appropriate critical value as well as for the threshold variables. The candidates for the inflation variables include three different moving averages (MA) with three different starting lagged inflation variables. See the Appendix for details.

A drawback to this single equation approach is that it fails to capture the dynamic interactions of output, price, money and credit conditions. Furthermore, the univariate process assumes that the inflation regime is exogenous. As mentioned in the introduction, it is possible that along with inflation itself, money, price or output shocks could influence inflationary conditions and, thus, affect overall economic activity. To capture these interactions, we have employed the TVAR model, in which the entire vector autoregression switches its structure, depending on the value of a measure of inflationary conditions. In the high-inflation regime, the interest rate is hypothesized to be positively correlated with an expansionary monetary policy, whereas the interest rate is hypothesized to drop whenever the same easy monetary policy is employed during the low-inflation regime.

This section generalizes the threshold model proposed above so as to incorporate the inflation regime into the dynamic system. Equation (1) is thereby generalized to a multivariate framework.

$$X_t = C^0(L)X_{t-1} + [C^1(L)X_{t-1}]I(\pi_{ct} > r) + \varepsilon_t \tag{3}$$

where X_t is a vector of the time series which includes variables representing monetary policy, the interest rate, output and price. Because π_{ct} is influenced by the price level, the TVAR describes both the evolution of X_t, as well as the inflation regimes. Restated, the inflation regime is determined endogenously. Once the threshold variable and its value are known, forecasts for each of the variables can be made.

The estimated threshold variable and the threshold value are determined by searching over π_{ct} and r so as to minimize $\log|\sum \varepsilon_t'\varepsilon_t|$, where ε_t is the vector of residuals from the TVAR. As in the univariate case, the threshold value, r, is restricted to allow the degrees of freedom to exceed 10.

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[4] Shen and Hakes (1995) have, however, used the arranged autoregression method to determine the threshold values.

Computing the IRF for TVAR, however, is not an easy task. Differing as it does from the conventional IRF, where the shock can be standardized, the effect of a shock in TVAR, as described above, may initially affect the system in one regime and then switch to another regime after sufficient accumulation of influence. Hence, computation of the IRF in the TVAR (hereafter, termed as nonlinear IRF, NIRF) is influenced by the history of the time series, as well as the size and magnitude of the shock [see Gallant et al. (1993); Potter (1995); Koop (1996); Balke and Chang (1996)]. The computing process relies heavily on the numerical analysis. Koop et al. (1996) described the steps involved in computing the NIRF by means of Monte Carlo integration. Their analysis focused on the asymmetric response of the variables to one standard deviation of positive and negative shocks. The NIRFs are defined in a manner similar to standard impulse response functions, except for replacing the standard linear predictor by a conditional expectation:

$$\mathrm{NLIRF}_n(\nu, y_t, y_{t-1}, \ldots) = E[Y_{t+n}|Y_t = y_t + \nu, Y_{t-1}, \ldots] - E[Y_{t+n}|Y_t = y_t, Y_{t-1}, \ldots], \quad (4)$$

where lower-case letters represent the realized values, and ν is the postulated impulse. Typically, the effect of a single exogenous shock is examined at a time. Therefore, the value of the ith element in ν, ν^i is set to a specific value; in particular, the monetary shock. In a linear framework, the response of a variable to shocks with different sizes and signs will be the same under suitable scaling. Hence, the response of a linear model can be summarized in a single diagram. In the case of the nonlinear IRF, the story is completely different.

The evolution of NIRF is influenced by the history of the time series, and the size and magnitude of the shock. For example, assume that a positive monetary shock occurs at time t in the low inflation regime. The falling interest rate then stimulates output and, consequently, increases the inflation rate. As time passes, the inflation may be so stimulated as to shift economic activities to a high-inflation regime. Investors thus form inflationary expectations which may overpower the liquidity effect. Response patterns are changed accordingly. As, over time, the response may shift back and forth between the two regimes, the size, the history and the magnitude of the shocks will influence the impulse response function. The conditional expectations, $E[Y_{t+n}|Y_t = y_t + \nu, Y_{t-1}, \ldots]$ and $E[Y_{t+n}|Y_t = y_t, Y_{t-1}, \ldots]$, must be calculated by simulating the model rather than projecting the model forward and setting the future shock equal to zero as in the linear model. A nice comparison between IRF and NIRF is presented by Koop et al. (1996).

A more relevant issue related to this study is that of assessing the responses of interest rate to monetary policy under different inflation regimes, rather than to the different sizes of shocks. Low- and high-inflation regimes are defined as follows. We employed the above model to simulate the initial conditions. The NIRF during the low (high)-inflation regime is obtained only when the initial state is in the low (high)-inflation regime after 500 periods. The average impulse response is obtained by averaging 500 replications for each regime. See Balke and Chang (1996) for details. For convenience, the investigation of the response under different regimes is referred to as a regime-NIRF.

TVAR Ordering

The ordering of our VAR system is based on the suggestion by Christiano and Eichenbaum (1992). There are basically two types of ordering in their model, depending on whether monetary policy is pegged to the quantity (the money stock) or the price (the interest rate). If the monetary policy pegs on the quantity, which is called M-rule, the ordering of the VAR is (M, R, P, Y). The money variable is assumed to be exogenous contemporaneously. Alternatively, if the monetary policy pegs on the price, which is called the R-rule, the ordering of the VAR is (R, M, P, Y). The interest rate is exogenous contemporaneously. Both these rules have been attempted here, with NBR and M1 being the monetary policy measures. As both of these rules reached similar conclusions, the results of only the M-rule are reported here.

In addition to the Christiano and Eichenbaum (1992) four-variable VAR, Christiano et al. (1994) also included a measure of commodity price to avoid what they called the “price puzzle”; namely, that a tight monetary policy leads to a high price level. However, the commodity price could not but be omitted here for two reasons. First, as the main concern of this paper is the response of the interest rate to monetary policy, the response of the price level is less relevant. Second, the degrees of freedom would be quickly exhausted during the high-inflation regime if more variables were added to the VAR system.

III. Data and Nonlinearity Tests

Monetary policy was proxied by NBR and M1, following the suggestion by Christiano and Eichenbaum (1992) and Christiano et al. (1994). Both the growth rate and the level from were determined for these two variables. The interest rate, output and price level were proxied by the Federal Funds rate (FFR), real GDP (GD) and the consumer price index (CPI), respectively. Quarterly data covering the period 1960:1–1996:3 were used. Except for the interest rate, all other variables were transformed logarithmically.

Once the data were constructed, the four nonlinearity tests discussed above were implemented. These tests served several purposes. First, they explored the nonlinear nature of the relations among the variables. Second, because different nonlinearity tests possess varying strengths of detecting different types of nonlinearities, these tests might shed some light on the nonlinear dynamics of the variables when the results of these tests are compared with each other.

Results of the nonlinearity tests based on equation (1) are presented in the top and bottom panels of Table 1 with respect to the growth rate of NBR and M1, respectively. The four nonlinear tests overwhelmingly rejected the linear hypothesis at the 1% level, regardless of the measures used to represent monetary policy. Furthermore, the rejections by TAR-F and GEN-F suggest that the series exhibit certain threshold nonlinearity.

Next, the levels of NBR and M1 were calculated. As the results did not change significantly, they are not reported here to save space. The existence of nonlinearity calls for the threshold estimation, as discussed in the next section.

IV. Results From the Univariate Process

Results obtained in this section serve as a benchmark for comparison purposes. A search of the critical values was made over the range of 5% to 9%. The maximum critical value was restricted to be below 9%, because of a restriction on the degrees of freedom. The lag length was selected to be three, based on the Akaike Information Criterion (AIC) for the linear specification. The critical value 8.15%, which minimizes the sum of residual

Table 1. Nonlinearity Tests Growth Rate of NonBorrowed Reserve

1. ORG-F (10, 127) (p value) = 11.79 (1×10^{-12})
2. AUG-F (10, 124) (p value) = 6.854 (2×10^{-7})

	3. TAR-F		4. GEN-F	
d	TAR-F	p value	GEN-F	p value
1	7.86775	2×10^{-012}	2.95580	2×10^{-012}
2	7.81518	3×10^{-012}	2.95823	2×10^{-012}
3	7.74079	4×10^{-012}	2.96083	2×10^{-012}
4	7.60254	7×10^{-012}	2.96373	2×10^{-012}
5	7.52483	1×10^{-011}	2.96680	2×10^{-011}
6	7.37977	2×10^{-012}	2.96991	2×10^{-012}
7	7.34772	2×10^{-012}	3.01882	1×10^{-012}
8	7.24959	3×10^{-012}	2.97214	2×10^{-012}
9	7.21734	4×10^{-012}	2.93068	3×10^{-012}
10	7.18501	5×10^{-012}	2.89247	3×10^{-012}
11	7.10121	7×10^{-012}	2.91432	3×10^{-012}
12	7.02293	1×10^{-011}	2.84950	5×10^{-011}

Growth Rate of M1

1. ORG-F (10, 127) (p value) = 16.90 (1×10^{-14})
2. AUG-F (10, 124) (p value) = 7.978 (2×10^{-10})

	3. TAR-F		4. GEN-F	
d	TAR-F	p value	GEN-F	p value
1	9.93865	3×10^{-015}	2.75690	5×10^{-005}
2	9.89866	3×10^{-015}	2.75913	5×10^{-005}
3	9.81464	5×10^{-015}	2.76145	5×10^{-005}
4	9.66819	9×10^{-015}	2.76390	4×10^{-005}
5	9.52951	2×10^{-014}	2.76634	4×10^{-005}
6	9.44725	2×10^{-014}	2.76857	4×10^{-005}
7	9.42801	3×10^{-014}	2.87602	2×10^{-005}
8	8.96740	1×10^{-013}	2.81720	4×10^{-005}
9	8.47665	6×10^{-013}	2.82801	4×10^{-005}
10	8.30470	1×10^{-012}	2.85587	4×10^{-005}
11	8.22582	2×10^{-012}	2.81402	5×10^{-005}
12	8.26346	2×10^{-012}	2.76894	7×10^{-005}

Note: ORG-F, AUG-F, TAR-F and GEN-F are defined in the text.

squares, was finally chosen as the inflation critical value. Furthermore, the critical variables were found to be π_{t-2}, $(\pi_{t-1} + \pi_{t-2})/2$ and $(\pi_{t-1} + \pi_{t-2} + \pi_{t-3})/3$.[5]

Once the critical value for NBR is determined, the univariate model can be implemented. The left side of Table 2 presents the estimation results using 8.15% as the critical value. Taking the first threshold variable of π_{t-2}, the sums of coefficients for monetary policy shocks in the two regimes were both insignificantly positive. These results do not fully lend support to our hypothesis, as no threshold behavior was detected. In contrast to this, results obtained by using the second and third threshold variables were encouraging.

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[5] The detailed searching processes and results are available upon request.

Table 2. Sum of Coefficients of Monetary Variables on Interest Rate: the Univariate Model

NBR Growth Sum of Coefficients			M1 Growth Sum of Coefficients		
Threshold Variable π_{ct}	Low Inflation Regime	High Inflation Regime	Threshold Variable π_{ct}	Low Inflation Regime	High Inflation Regime
π_{t-2}	0.0040	0.0034	π_{t-2}	0.0182	0.1849
	(0.388)	(0.071)		(0.869)	(0.537)
$(\pi_{t-1} + \pi_{t-2})/2$	−0.0048	0.1401	$(\pi_{t-3}+\pi_{t-4})/2$	0.0142	0.1474
	(0.404)	(2.647)		(0.682)	(0.534)
$(\pi_{t-1} + \pi_{t-2} + \pi_{t-3})/3$	−0.0017	0.1793	$(\pi_{t-3}+\pi_{t-4}+\pi_{t-5})/3$	0.0124	0.1827
	(0.105)	(3.643)		(0.607)	(0.603)

Note: Absolute *t* value in parentheses.

For example, while the sum of the coefficients was insignificantly negative during the low-inflation regime, the coefficients were significantly positive during the high-inflation regime. The confirmation obtained from these two threshold variables thus strongly supports our hypothesis. On average, the results shown in the left panel of Table 2 apparently favor the notion that monetary policy shocks have impacts on interest rates depending on the regimes. Though the results seem sensitive to the threshold variables employed, there is no real evidence to support the converse proposition that an easy monetary policy increases the interest rate.

The results obtained from using M1 growth are presented on the right side of Table 2, using a similar method to locate the threshold variables and critical values. In contrast to our hypothesis that money is expected to affect the interest rate differently across regimes, the responses were insignificantly positive regardless of the regimes. Thus, the M1 type monetary policy shocks had no influence on interest rates. This unexpected result motivated the use of the multivariate model of the next section.

V. Results From the Multivariate Process

One major drawback of the single-equation approach is that it fails to capture the dynamic interaction of the interest rate, money, output, price level and inflation. The inflation regime, which probably affects the response of the interest rate to money, can also be affected by the manner in which the interest rate is affected. To capture these interactions, we tested the TVAR in which the entire vector autoregression changed its structure depending on the value of a measure of inflationary conditions.

Linear IRF

We first present the IRF of the conventional VAR model in Figure 2. The VAR includes four variables, viz., the interest rate, NBR (M1) growth, real GDP, and the price level. The lag length of our VAR is three. The ordering of the VAR follows the M-rule above. The results of the R-rule ordering are not reported for the sake of brevity. The responses of interest rates to NBR and M1 growth are plotted at the top and bottom of Figure 2, respectively. At the top of Figure 1, the interest rates drop initially and rise gradually in response to the impact of NBR growth shock. At the bottom of Figure 2, the interest rate

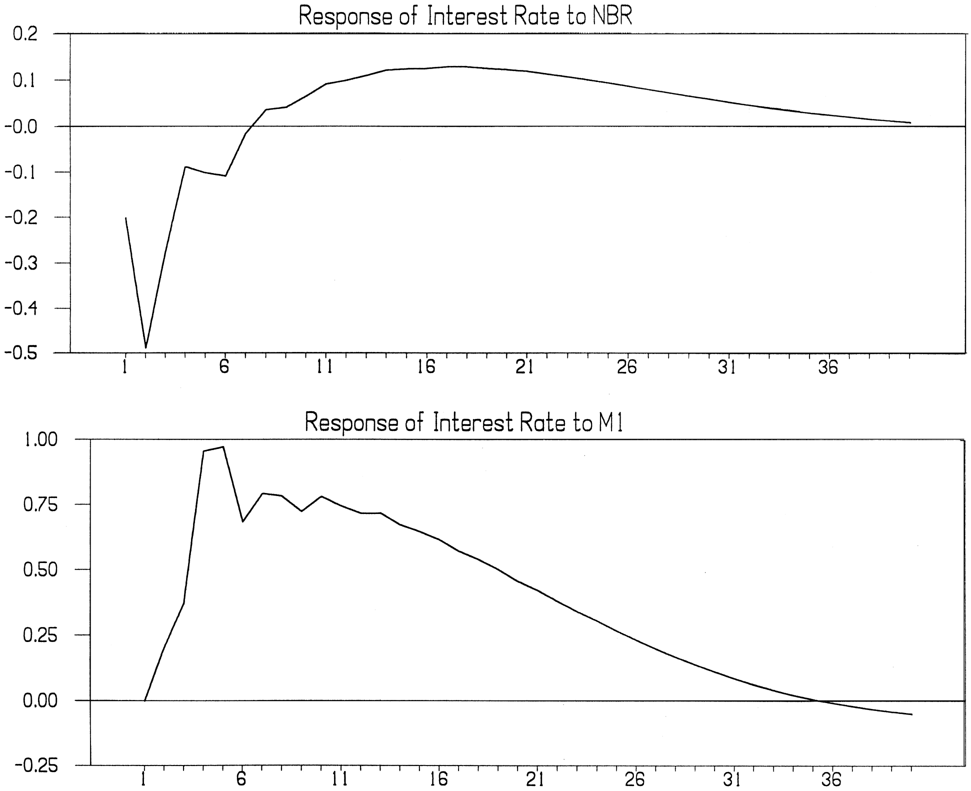

Figure 1. Linear Impulse Response Function.

rises immediately, due to the impact of M1 growth shock. These responses are consistent with the literature, in that the liquidity effect vanishes if monetary policy is measured by M1 [Leeper and Gordon (1992); Christiano and Eichenbaum (1992)], whereas a liquidity effect can be detected if NBR is employed [Christiano and Eichenbaum (1992); Strongin (1995)].

Determination of the Threshold Value

The threshold variable and the critical values were estimated before computing the NIRF of TVAR. Various threshold variables, π_{ct}s, and the critical values, rs, were estimated and are plotted in Figure 2. The threshold variable and critical value, that is, $(\pi_{t-1} + \pi_{t-2})/2$ and (8.15%), which minimize the sum of squares of residuals were adopted. Tables 3 and 4 report the linear and TVAR estimation results, using NBR and M1 growths as the monetary policy, respectively. In the linear case (the first column) of Table 3, the coefficients of the lagged one, two and three periods of NBR growth were not significantly different from zero and were negative after the lagged two periods of NBR. The results changed dramatically when the TVAR was employed. For the lower-inflation regime, the coefficients of lagged NBR growths were overwhelmingly negative. The coefficients became mostly positive during the high-inflation regime.

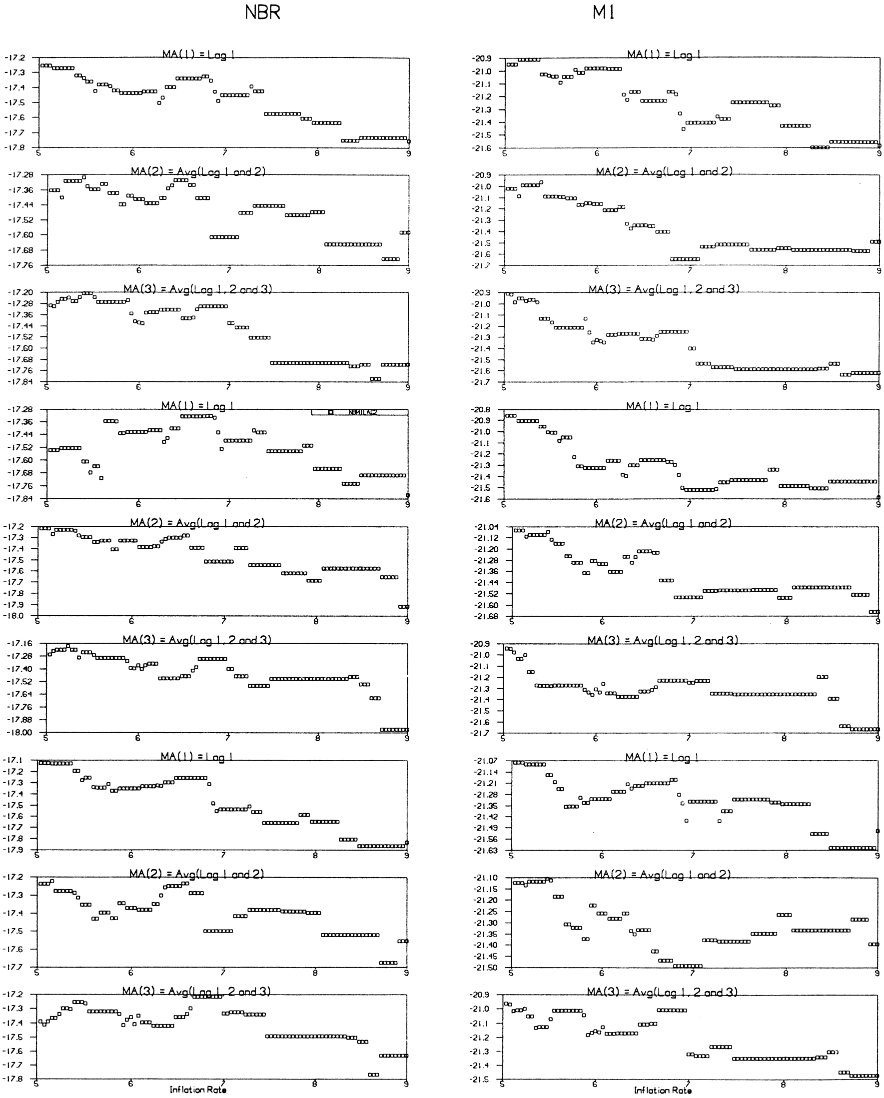

Figure 2. Residual of Vector Sum of Squares: Multivariate Process.

The results of Table 4, which used M1 growth as the proxy of monetary policy, are different from those of Table 3. Except for the $M1_{t-2}$ growth in the linear and lower-inflation regime, all coefficients on lagged M1 growth were positive. These results shed light on the importance of threshold behavior, especially when the NBR is employed to represent the monetary policy.

In order to gain insight as to how monetary policy shocks affect the interest rate, the NIRF was computed. However, the nonlinear structure of this model makes the NIRF and variance decomposition analysis substantially more complex than the linear model. The computing process is thus extremely time-consuming. Also, the contemporaneous VAR/COV matrix of the residuals were allowed to change across regimes [see Balke and Chang

Table 3. Using NBR Growth As Monetary Policy

		Threshold Model	
Variable	Linear Model	Lower-Inflation Regime	Higher-Inflation Regime
Constant	−0.245	−1.083	−0.003
	(1.076)	(0.923)	(0.017)
NBR_{t-1}	0.00001	−0.002	0.003
	(0.020)	(0.106)	(0.725)
NBR_{t-2}	−0.0001	−0.0151	−0.002
	(0.200)	(0.830)	(0.493)
NBR_{t-3}	−0.0005	−0.013	0.0004
	(0.120)	(0.652)	(0.135)
$Tbill_{t-1}$	1.148*	1.217*	1.334*
	(12.063)	(5.149)	(12.622)
$Tbill_{t-2}$	−0.626*	−0.813*	−0.711*
	(4.604)	(2.522)	(4.889)
$Tbill_{t-3}$	0.384*	0.554*	0.284*
	(3.848)	(2.110)	(3.129)
$Infla_{t-1}$	−0.050	0.346*	0.046
	(1.143)	(2.247)	(1.278)
$Infla_{t-2}$	0.200*	0.587*	0.063
	(4.072)	(3.133)	(1.740)**
$Infla_{t-3}$	−0.035	−0.082	−0.038
	(0.784)	(0.524)	(1.127)
$RGDP_{t-1}$	0.048*	0.142*	0.036*
	(2.451)	(2.361)	(2.341)
$RGDP_{t-2}$	0.052*	0.068	0.026***
	(2.701)	(1.166)	(1.725)
$RGDP_{t-3}$	0.005	−0.028	0.010
	(0.263)	(0.528)	(0.657)
N	143	108	34
Adjusted R^2	0.928	0.952	0.855

*, **, *** denote significance at the 1%, 5% and 10% level, respectively.
N is the number of observations.

(1996)]. As the NIRF is influenced by the history of variables—the size and magnitude of the shocks—the response of the interest rate to the monetary shock cannot be summarized in a single IRF plot, in contrast to the conventional linear case. Rather, we generated the positive and negative, one and two standard deviation shocks, respectively. The regime-NIRF will be discussed next.

Regime-NIRF

Our proposition claims that the liquidity effect revives in the low-inflation regime but vanishes in the high-inflation regime. We therefore calculated the average impulse response functions, conditional on the initial state being in the low- or high-inflation regimes. This calculation was performed by simulating the model (taking the actual sample means as start-up values) and taking the 500*th* observations as the initial condition. Then, we calculated the response in the low (high) regime. Because the impulse response function is likely to be different depending on the past history of the variables, this

Table 4. Using M1 Growth As Monetary Policy

		Threshold Model	
Variable	Linear Model	Lower-Inflation Regime	Higher-Inflation Regime
Constant	−0.269	0.009	−2.800*
	(1.186)	(0.053)	(2.279)
$M1_{t-1}$	0.028	0.008	0.253*
	(1.200)	(0.410)	(2.751)
$M1_{t-2}$	−0.043***	−0.020	0.140
	(1.787)	(0.978)	(1.296)
$M1_{t-3}$	0.028	0.014	0.036
	(1.279)	(0.822)	(0.351)
$Tbill_{t-1}$	1.175*	1.311*	0.901*
	(13.109)	(13.614)	(3.830)
$Tbill_{t-2}$	−0.613*	−0.688*	−0.201
	(4.331)	(4.978)	(0.565)
$Tbill_{t-3}$	0.343*	0.287*	0.170
	(3.112)	(2.990)	(0.595)
$Infla_{t-1}$	−0.035	0.053	−0.283*
	(0.811)	(1.483)	(2.235)
$Infla_{t-2}$	0.172*	0.051	0.473*
	(3.467)	(1.336)	(2.612)
$Infla_{t-3}$	−0.029	−0.041	−0.039
	(0.657)	(1.122)	(0.277)
$RGDP_{t-1}$	0.043*	0.034**	0.015
	(2.205)	(2.170)	(0.211)
$RGDP_{t-2}$	0.052*	0.028***	0.027
	(2.767)	(1.797)	(0.464)
$RGDP_{t-3}$	−0.001	0.007	−0.012
	(0.069)	(0.511)	(0.272)
N	143	108	34
Adjusted R^2	0.930	0.952	0.889

*, **, *** denote significance at the 1%, 5% and 10% level, respectively.
N is the number of observations.

response was replicated 500 times and the average impulse response function was then obtained. This average NIRF represents the response of the interest rate to the monetary policy shock conditional on the regime.

Figure 2 depicts the responses of interest rate to the NBR shock, which can be seen to be indeed different across inflation regimes. As can be noted from the top panel of the figure, expansionary shocks (i.e., positive NBR growth) of two standard errors, which is represented by the dark black line, depressed the interest rate over the initial ten periods during the low-inflation regime, and the response became sufficiently close to zero after 11 periods. A strong liquidity effect is thus evident. When a smaller shock, i.e., of one standard error, was considered, the responses were mitigated; however, the response patterns did not change. The vanishing liquidity effect, as claimed by Mehra (1985), Leeper and Gordon (1992) and Christiano and Eichenbaum (1992), is thus retrieved during the low-inflation regime.

In contrast to the negative responses in the low-inflation regime, the bottom panel of Figure 2, i.e., the high-inflation regime, displays a completely different scenario. During this regime, the interest rate responded negatively to the expansionary monetary policy

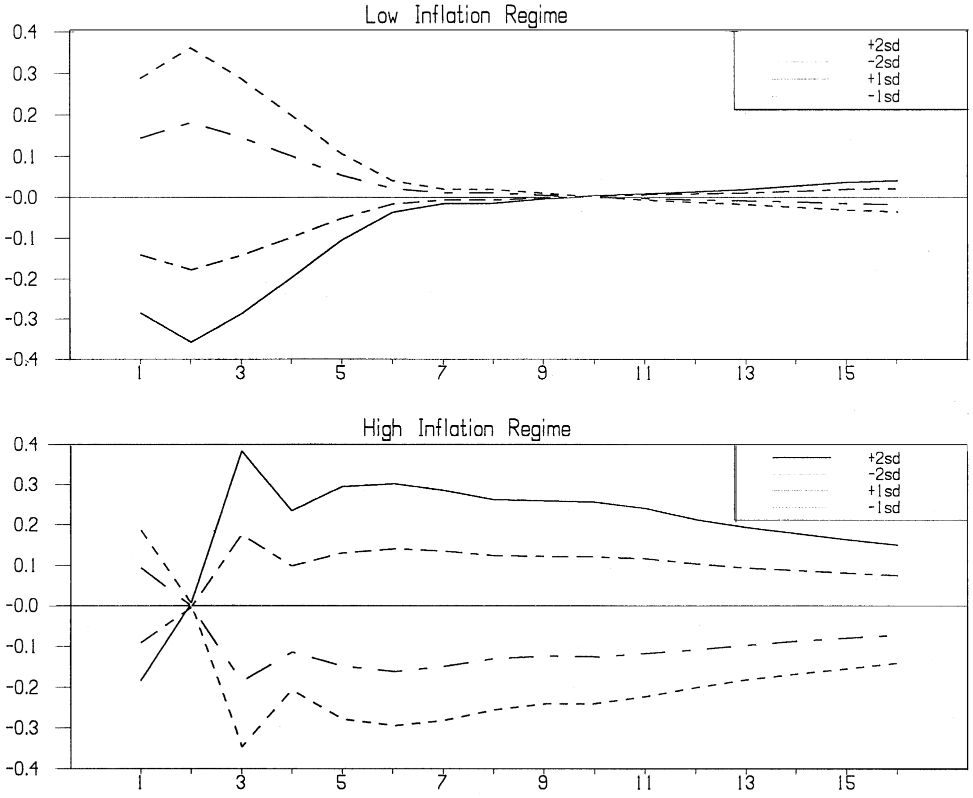

Figure 3. Response of Interest Rate to Non-Borrowed Reserve.

shock (dark black line) for just one period. The responses then became positive for the remaining fifteen periods. The inflationary expectation effect can thus be observed to be strong enough to overpower the liquidity effect during the high-inflation regime. As the liquidity and inflationary expectations effects dominated in the low- and high-inflation regimes, respectively, these results strongly support our hypothesis.

Previous investigations have contended that the response of the interest rate to monetary policy is sensitive to the choice of monetary measure [Normandin and Phaneuf (1996)]. Hence, the following exercise used M1 growth as our monetary policy measure. As the liquidity effect is typically refuted in the literature when M1 growth is used [Leeper and Gordon (1992); Christiano and Eichenbaum (1992)], the results of using M1 growth, if consistent with our hypothesis, can further verify threshold behavior.

Figure 3 depicts the responses of the interest rate to an M1 growth shock. In the top panel of the figure, the low-inflation regime, i.e., the expansionary monetary policy of two standard errors (dark black line), can be seen to have depressed the interest rate for the initial five periods and then to have made it positive for the remaining periods. In contrast to the long-lasting negative response obtained using NBR (ten-period), the liquidity effect was relatively short-lived in this case (five-period). Although the negative responses were relatively short-lived compared to those in the NBR case, they were long enough, compared to those reported in the literature. The liquidity effect is typically reported to be nonexistent in the literature if M1 is employed. Hence, the five-period negative responses are deemed supportive, though weakly, of our argument. Previous rejection of the liquidity effect using NBR and M1 growth may admittedly ignore the threshold behavior.

The response of the interest rate was completely reversed during the high-inflation regime. In the bottom panel of Figure 3, the interest rate can be seen to have declined for just one period and then to have risen above zero for the remaining 13 periods. This suggests that the monetary policy shock affected the interest rate positively during the high-inflation regime, which is again consistent with our hypothesis.

Sign-NIRF

In order to better illuminate the dynamics of our model, a second impulse response function was also calculated. Based on the proposed threshold behavior, it was interesting to compute the responses when the initial condition was essentially drawn from an unconditional distribution; that is, responses of the interest rate when a monetary policy shock impacts the system randomly, instead of being conditional on a given regime. This analysis was carried out by simulating the model and taking the 500*th* observation as the initial condition. We then examined the response of the system to shocks with different signs and sizes.

Specifically, conditional expectations were calculated by randomly drawing vectors of shocks, ν_{t+i}, $i = 1$ to k, and then simulating the model, depending on the initial conditions and a given realization of ν_t. To eliminate any possible asymmetric effect which might have arisen from variation in the sampling due to the random draws of $\dot{\nu}_{t+i}$, the simulation for negative shock, $-\nu_{t+i}$, was repeated. The simulations were further repeated 100 times for both positive as well as negative shocks. The resulting average was then taken as the conditional expectation. From this, we can assess the response of the interest rate to both positive and negative monetary shocks. As these responses involved shocks with different signs, the response function is referred to as a sign-NIRF.

The results of the sign-NIRF, obtained by using growth in nonborrowed reserves and M1, are plotted in the top and bottom of Figure 4, respectively. By employing NBR, the response of the interest rate was negative for the first 12 periods. The liquidity effect was even short-lived (five-period) when M1 was adopted. Both of these plots are consistent with the results reported in the literature that the liquidity effect is stronger for nonborrowed reserves than for M1.

VI. Conclusion

The threshold vector autoregressive model proposed in this study successfully separated the economy into a low-inflation regime and a high-inflation regime. Monetary policy was endogenized in this framework and two different measures of monetary policy, NBR and M1, were adopted. In the low-inflation regime, an expansionary monetary policy shock depressed the interest rate over ten and five periods for nonborrowed reserves and M1 growth, respectively. The previously rejected liquidity effect was ultimately reviewed during this regime. In the high-inflation regime, the inflationary expectations effect dominated the liquidity effect for almost the whole period, regardless of the monetary measures. These results, thus, strongly support the threshold behavior hypothesis.

The results presented herein may shed light on the transmission mechanism of monetary policy in different inflationary environments. In a low-inflation regime, money may

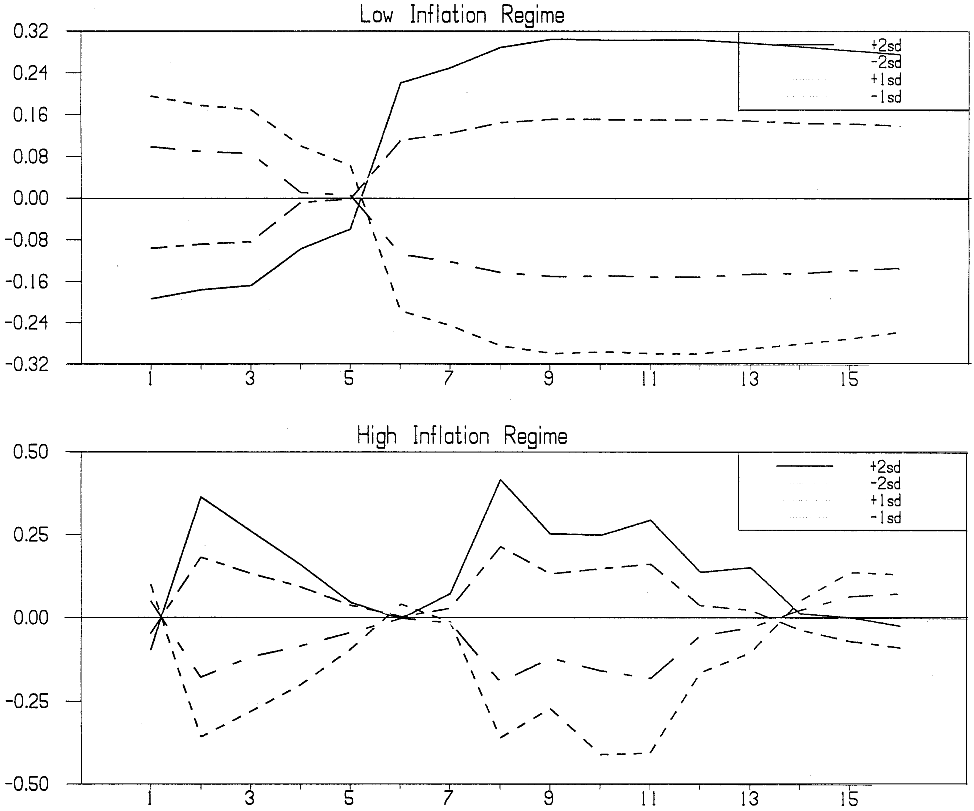

Figure 4. Response of Interest Rate to Money Supply 1.

not be neutral, as it could affect output through the liquidity effect. However, this channel breaks down for the high-inflation regime, as inflationary expectations are immediately responsive to money growth. Thus, changes in money do not appear to affect output through the liquidity effect in the high-inflation regime.

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Appendix

This appendix describes the procedures involved in searching for the critical values and the threshold variables based on criterion (2).

When $k = 1$, $d = 1, 2, 3$, $MA(1)$ contains three cases of π_{t-1}, π_{t-2} and π_{t-3}, respectively. When $k = 2$, $d = 1, 2$, $MA(2)$ contains three cases of $(\pi_{t-1} + \pi_{t-2})/2$, $(\pi_{t-2} + \pi_{t-3})/2$, and $(\pi_{t-3} + \pi_{t-4})/2$, respectively. Finally, when $k = 3$, $d = 1$, $MA(3)$ also contains three similar cases. For each moving average, we chose the threshold variable which yielded the lowest residual sum of squares. Because the inflation rate has typically

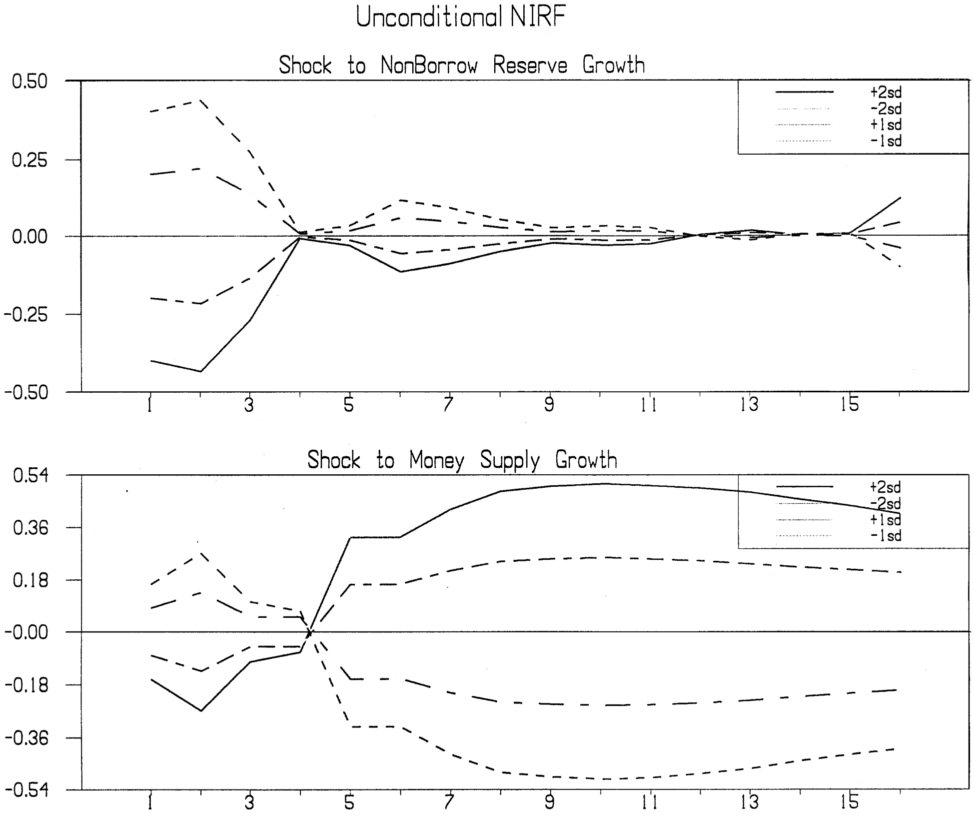

Figure 5. Response of Interest Rate to Different Money Measures.

been below 5% since 1985, the observations in the two regimes may be unbalanced if the critical value *r* is high. Therefore, in order to permit sufficient observations to be estimated in each regime, the critical value, *r*, was restricted to allow the degrees of freedom to exceed 10.

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